

The Advantages of Non-Flow-Through Fuel Cell Power Systems for Aerospace Applications

NASA has been developing proton-exchange-membrane (PEM) fuel cell power systems for the past decade, as an upgraded technology to the alkaline fuel cells which presently provide power for the Shuttle Orbiter. All fuel cell power systems consist of one or more fuel cell stacks in combination with appropriate balance-of-plant hardware. Traditional PEM fuel cells are characterized as flow-through, in which recirculating reactant streams remove product water from the fuel cell stack. NASA recently embarked on the development of non-flow-through fuel cell systems, in which reactants are dead-ended into the fuel cell stack and product water is removed by internal wicks. This simplifies the fuel cell power system by eliminating the need for pumps to provide reactant circulation, and mechanical water separators to remove the product water from the recirculating reactant streams. By eliminating these mechanical components, the resulting fuel cell power system has lower mass, volume, and parasitic power requirements, along with higher reliability and longer life. These improved non-flow-through fuel cell power systems therefore offer significant advantages for many aerospace applications.



The Advantages of Non-Flow-Through Fuel Cell Power Systems for Aerospace Applications

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NASA PEMFC Development History



- NASA initiated PEMFC studies during Shuttle upgrade program in late 1990's at JSC
 - High DDT&E costs prevented switch from alkaline to PEM, in spite of several technical advantages
- RLV program funded initial development of PEMFC technology (2001)
 - A single vendor selected
- RLV transitioned into NGLT, SLI, and eventually ETDP programs (2001-2007)
 - Two vendors selected for Breadboard development
 - One vendor down-selected for Engineering Model development
 - Disadvantages of flow-through PEMFC systems became evident during testing of Engineering Model; **balance-of-plant experienced multiple failures (rotating mechanical components)**
- Began investigation of “passive” balance-of-plant concepts for flow-through technology (2005)
 - Reactant pumps replaced with injectors/ejectors
 - Mechanical water separators replaced with membrane water separators
- In parallel, began investigation of non-flow-through technology through SBIR program (2005)
 - **Single vendor awarded contract**
- **Down-selected to non-flow-through technology over flow-through technology; initiated in-house development of balance-of-plant (2008)**

Fuel Cell Technology Development Mission Requirements Assessment



Lunar Architecture Studies identified regenerative fuel cells and rechargeable batteries as enabling technology, where enabling technologies are defined as having:
“overwhelming agreement that the program cannot proceed without them.”

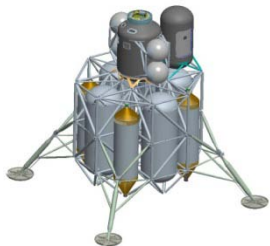
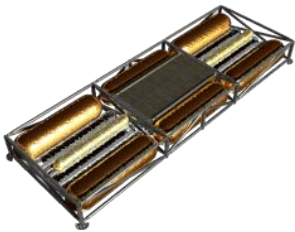
Surface Systems

Surface Power: Maintenance-free operation of **regenerative fuel cells** for >10,000 hours using ~2000 psi electrolyzers. Power level TBD (2 kW modules for current architecture)
Reliable, long-duration maintenance-free operation; human-safe operation; architecture compatibility; high specific-energy, high system efficiency.

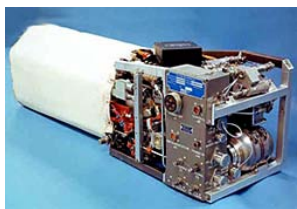
Mobility Systems: Reliable, safe, secondary batteries and **regenerative fuel cells** in small mass and volume.
Human-safe operation; reliable, maintenance-free operation; architecture compatibility; high specific-energy.

Lander

Descent Stage: Functional **primary fuel cell** with 5.5 kW peak power.
Human-safe reliable operation; high energy-density; architecture compatibility (operate on residual propellants).



Shuttle “Active BOP” Alkaline



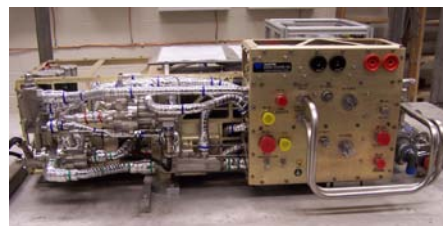
Flow-Through

“Active BOP” PEM



Flow-Through

“Passive BOP” PEM

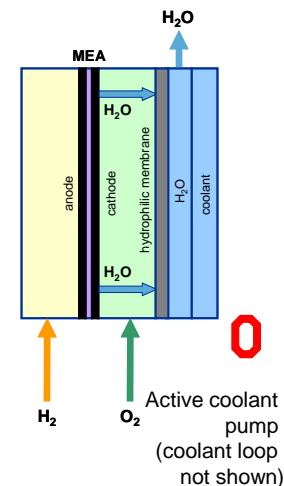
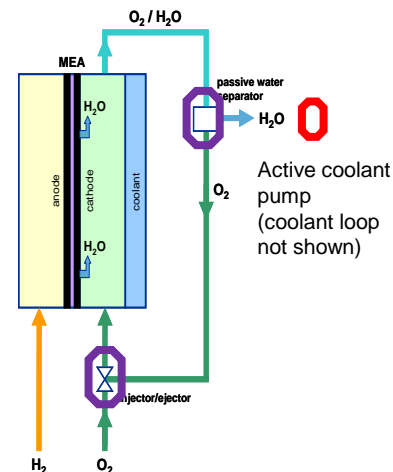
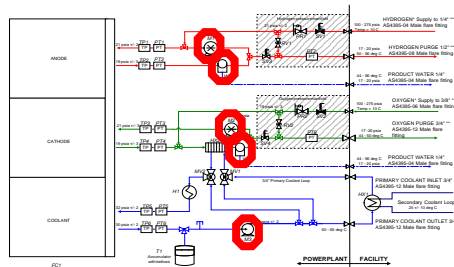
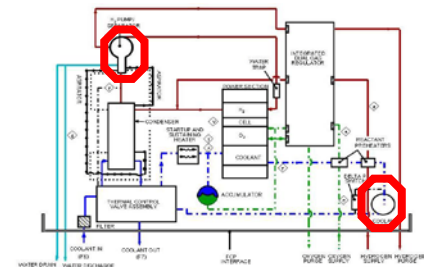


Flow-Through


“Passive BOP” PEM



Non-Flow-Through



 = Active Mechanical Component
(pump, active water separator)

 = Passive Mechanical Component
(injector/ejector, passive water separator)

Fuel Cell Technology Progression to Simpler Balance-of-Plant

Fuel Cell Technical Approach: “Non-Flow-Through” Water Management



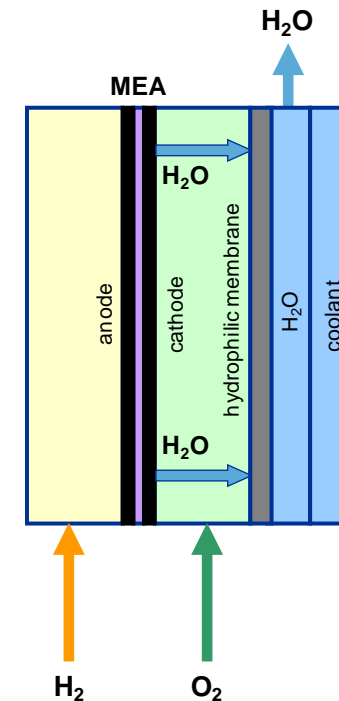
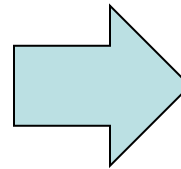
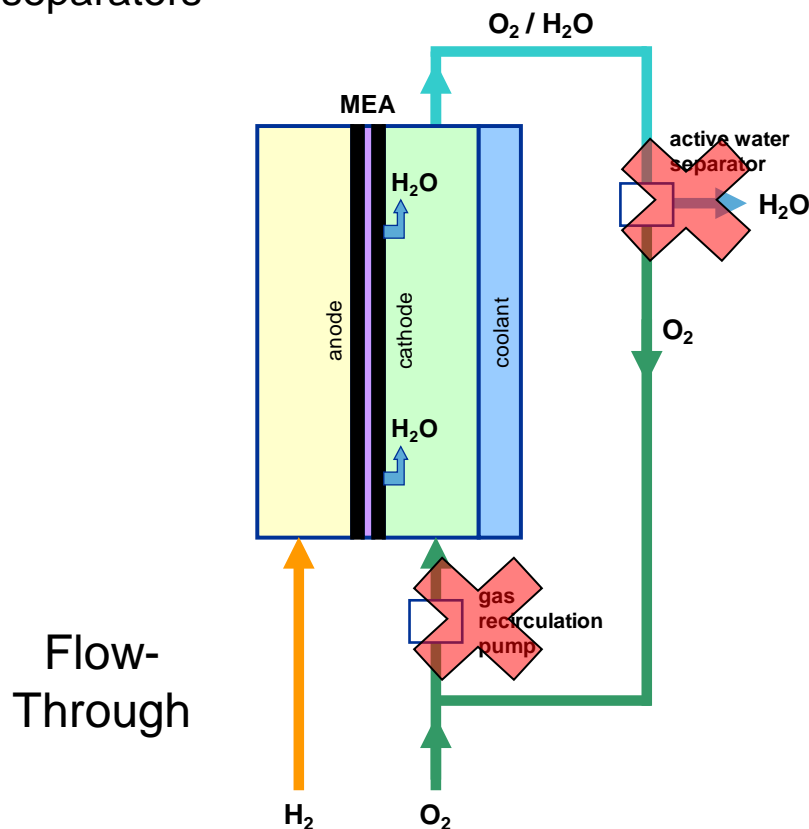
Develop “non-flow-through” proton exchange membrane fuel cell technology to improve system-level mass, volume, reliability, and parasitic power

Flow-Through components eliminated in Non-Flow-Through system include:

- Pumps or injectors/ejectors for recirculation
- Motorized or passive external water separators

Non-Flow-Through PEMFC technology characterized by dead-ended reactants and internal product water removal

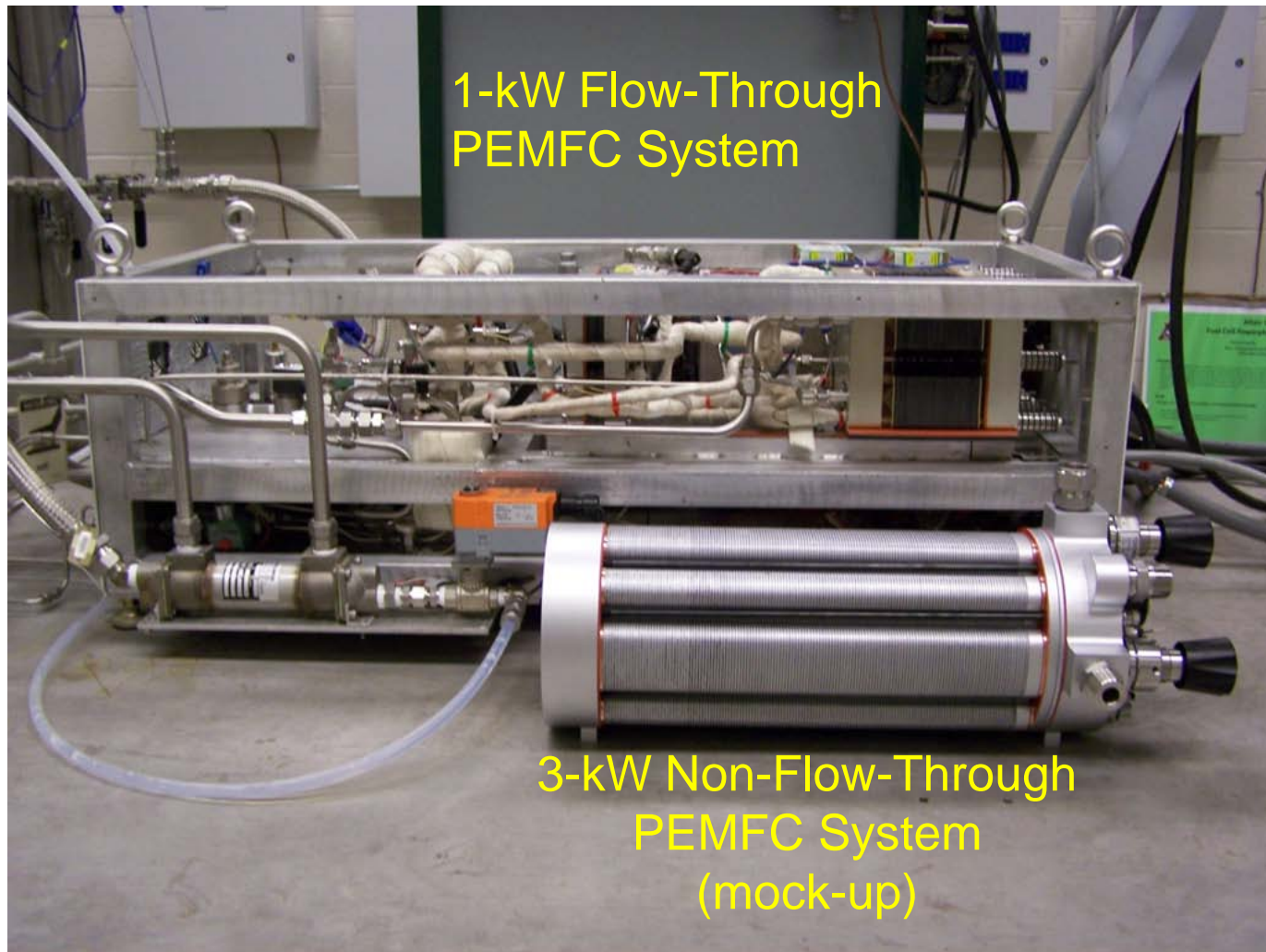
- Tank pressure drives reactant feed; no recirculation
- Water separation occurs through internal cell wicking



System-Level Comparison of Flow-Through vs. Non-Flow-Through PEMFC Technology



Design Parameter	Flow-Through	Non-Flow-Through
Efficiency	–	–
Mass		✓
Volume		✓
Parasitic Power		✓
Reliability		✓
Reactant Utilization		✓
Equivalent Reactant Storage “Depth-of-Discharge”		✓
Life		✓
Cost		✓
TRL	✓	



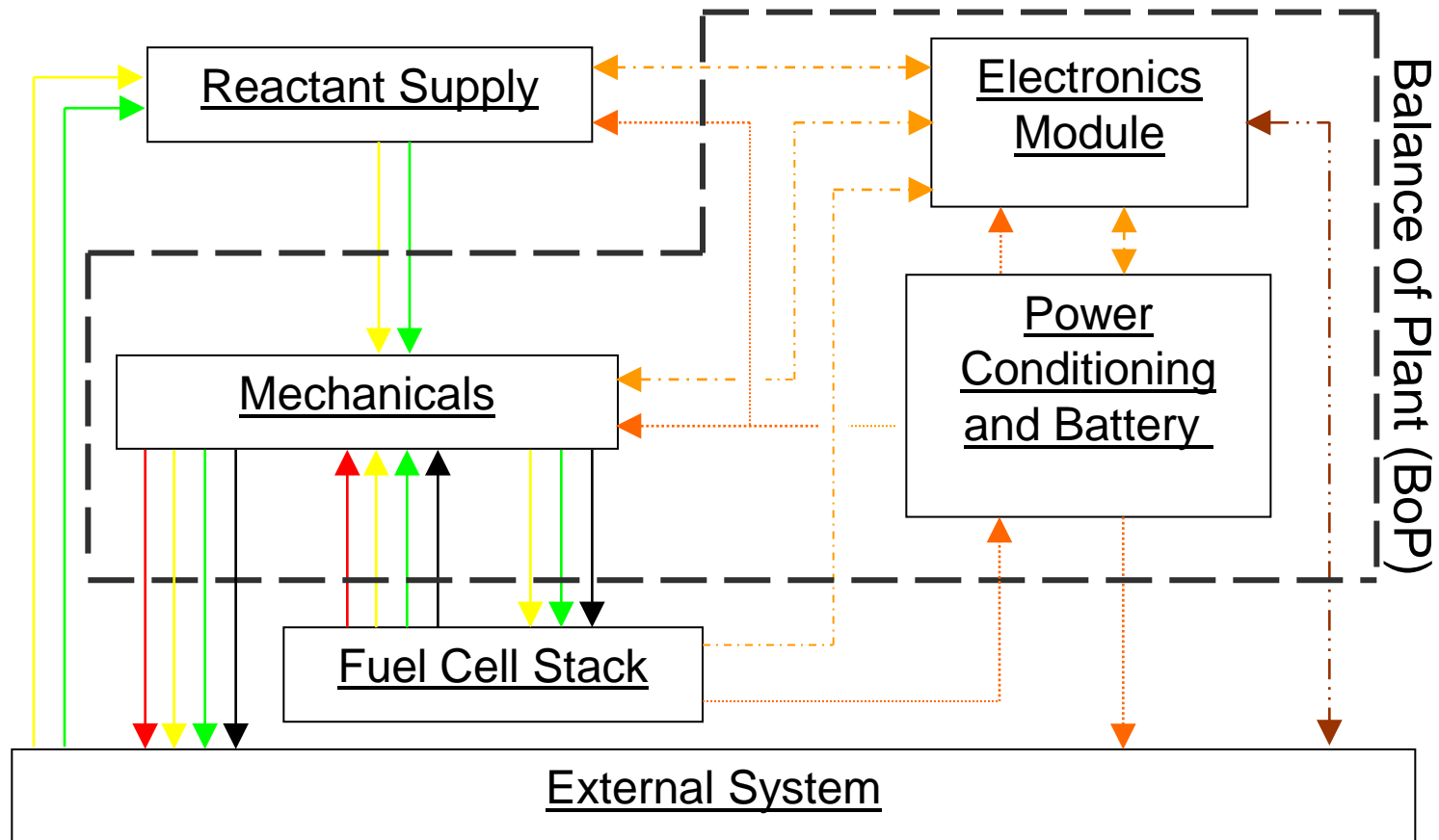
Non-flow-through PEMFC system has a substantially simpler balance-of-plant than conventional flow-through PEMFC system.

This offers significant advantages.

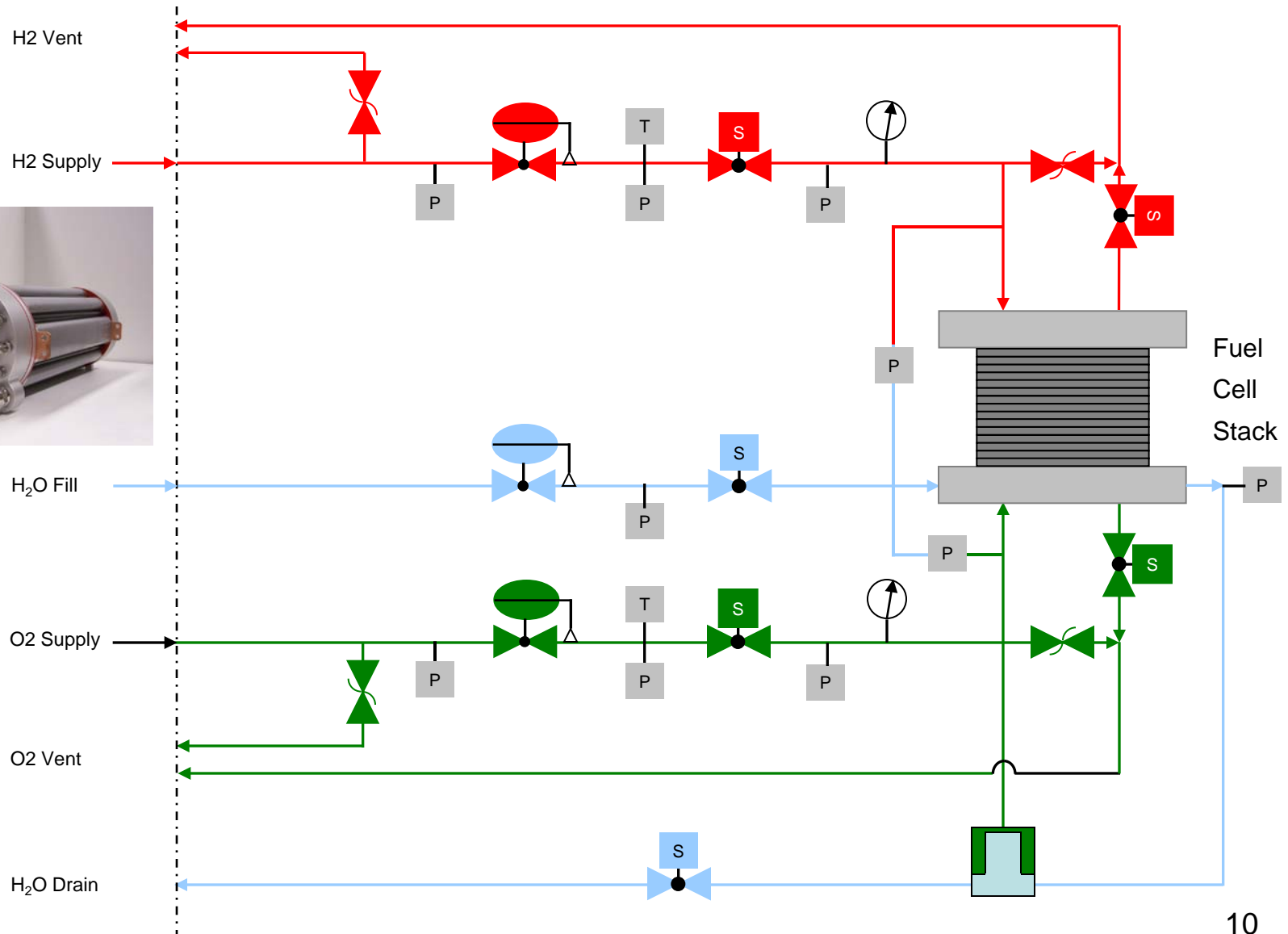


- Infinity selected as “baseline” non-flow-through PEMFC vendor very early in program
 - Awarded very first non-flow-through Phase I SBIR (2005)
 - Demonstrated development success led to Phase II and Phase III contract awards
 - Very advanced and robust cell technology
 - Excellent cell performance
 - Superior water removal
 - Knowledgeable team with extensive flight hardware development experience (Shuttle, Apollo, Gemini)
- Other subsequent SBIR and IPP vendors competed for “alternate” role
 - ElectroChem, Proton, and Teledyne stacks all experienced water management issues
 - ElectroChem & Teledyne most promising “alternate” technologies

Non-Flow-Through PEMFC System



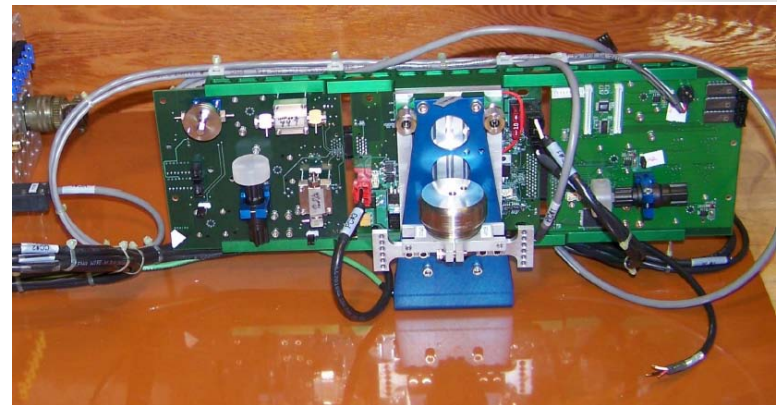
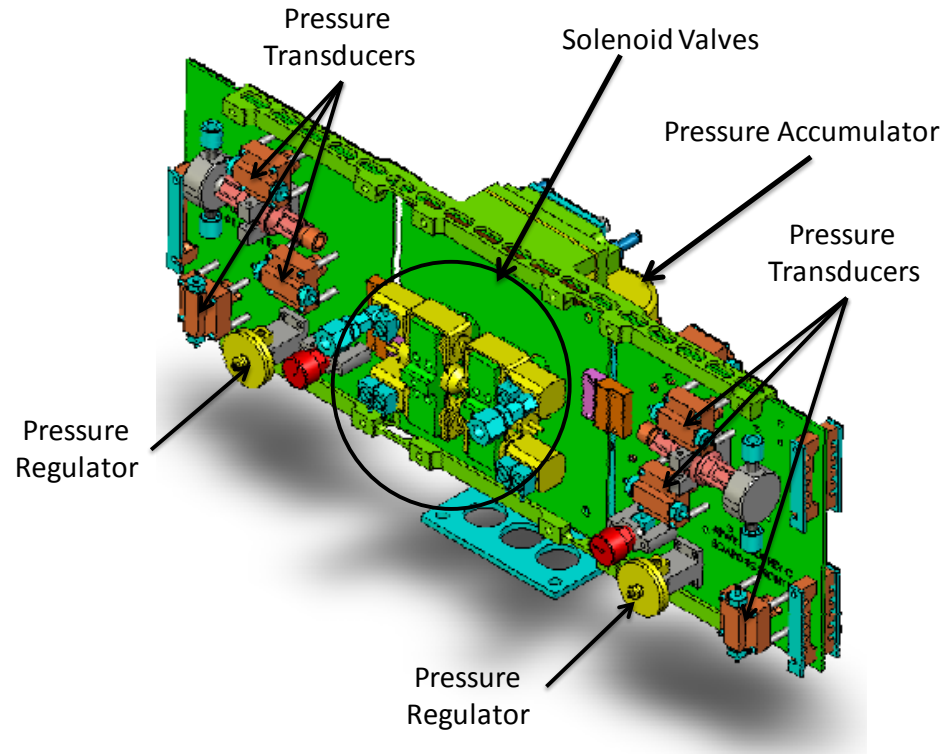
Non-Flow-Through PEMFC System Schematic



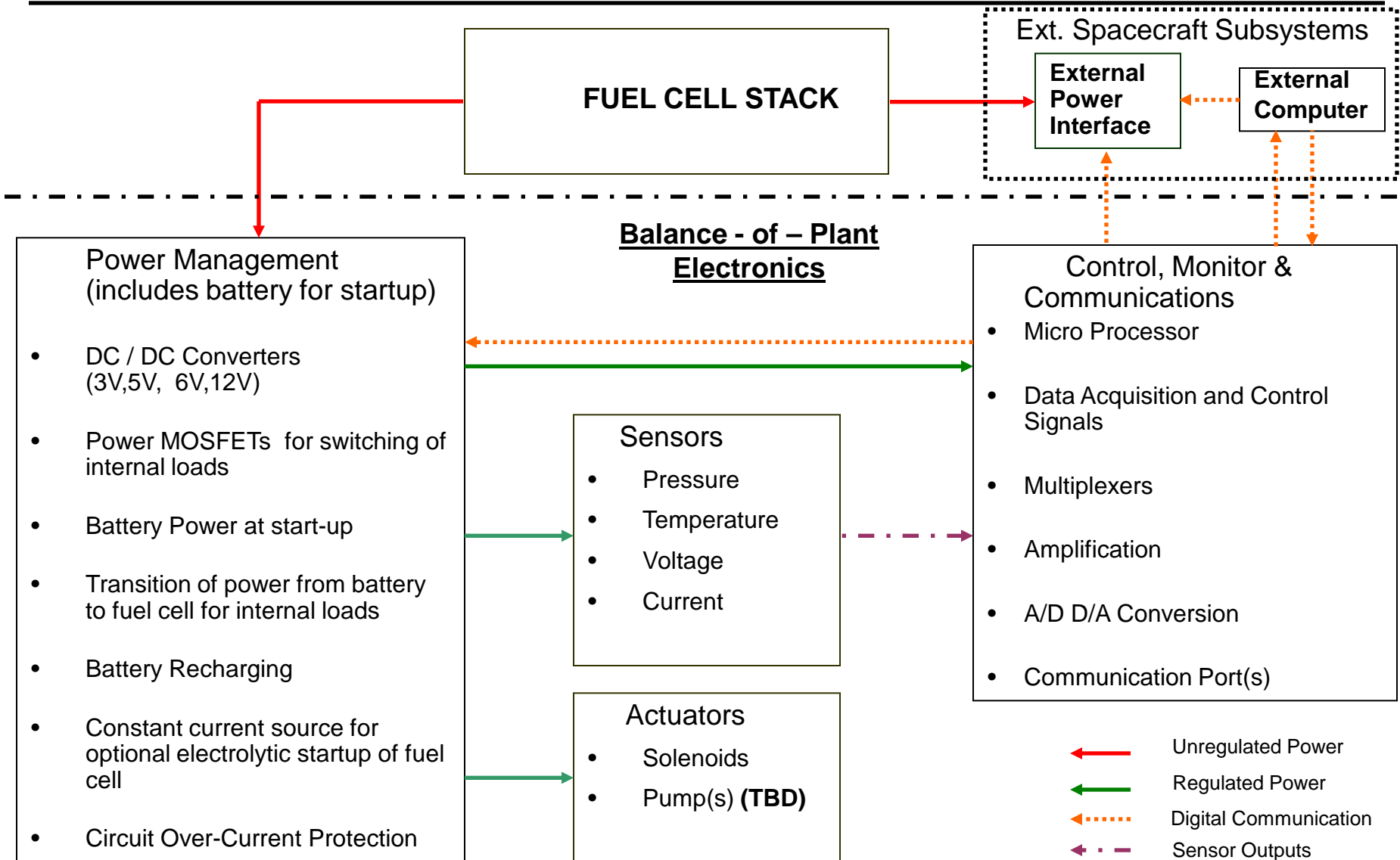
Small Fuel Cell System Balance-of-Plant Components for Fuel Cells



- Integrated balance-of-plant demonstrated in conjunction with the laboratory scale fuel cell stacks
- During this testing, the balance-of-plant ran on a battery source consuming only 10 watts of parasitic power to operate the fuel cell system
- A full-scale (3-kw fuel cell system) balance-of-plant will likely operate on only 50 watts or less of parasitic power (same number of components, but some components larger)



Non-Flow-Through PEMFC Electronic Interface



Future Activities – Flight Hardware



- Passive Water Control
- Advanced Thermal Control Systems
- Non-Flow-Through Reactants
- Integrated Fluidics
 - Endplate manifold houses all process fluid plumbing and fluidic measurement and control components
- Thermally compensated bolts eliminating Belleville washer stack-up
- Power
 - Nominal output power: 3 kW_e
 - Peak output power: 6 kW_e
 - Parasitic Power: 15 W to 35 W
- Envelope
 - Length: 60 cm (24 inches)
 - Width: 39.4 cm (15.5 inches)
 - Height: 25 cm (9.8 inches)
 - Weight: TBD (estimated 75 kg)

